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ESSAY

ON

COMPARATIVE PETROLOGY.

BY

M. J. DUROCHER,
MINING ENGINEER, AND PROFESSOR OF THE FACULTY OF SCIENCE AT RENNES.

TRANSLATED FROM THE "ANNALES DES MINES," VOL. XI., 1857,

BY

THE REV. SAMUEL HAUGHTON, M. A., F. R. S.,
FELLOW OF TRINITY COLLEGE,
AND PROFESSOR OF GEOLOGY IN THE UNIVERSITY OF DUBLIN.

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M^cGLASHAN & GILL, 50, UPPER SACKVILLE-STREET.
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Price One Shilling.

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Printed at the University Press,
BY M. H. GILL.

COMPARATIVE PETROLOGY.

Object of the Memoir.—This Essay gives the general results of a series of researches in which I have been engaged for a long time on the igneous rocks, and which are not yet completed; some of them, however, have already appeared in various journals, viz., "Voyages en Scandinavie," "Comptes rendus de l'Academie des Sciences" (tom. xx. p. 1277; tom. xxiii. p. 978; tom. xxv. p. 208; and tom. xliv. pp. 325, 459, &c., &c.); the "Bulletin de la Societé Geologique" (2nd ser. tom. iv. pp. 409, 1018; and tom. vii. p. 276); and the Memoirs of the same Society (2nd ser. tom. vi. first part).

For many years the eruptive rocks have been the subject of important investigations, both in France and Germany; but these investigations have only given rise to works of detail, of which the object is to determine the mineral species found in the rocks. The present Essay is a "Memoir on Comparative Petrology," and ought to be considered as an attempt at a general synthesis of the pyrogenous rocks, considered in the fourfold point of view,—of their Chemical constitution, their Mineralogical composition, their Eruption, and their Classification.

Part I.

REDUCTION OF ALL THE IGNEOUS ROCKS TO TWO MAGMAS.

Office of Silicon in the Mineral Kingdom.—In the mineral kingdom Silicon performs a part analogous to that of carbon in the organic kingdom; and in its behaviour, as a polybasic acid, silica unites with the oxides in various proportions, and thus gives rise to numerous combinations. Most of the mineral species which thence result, and especially those which enter into the composition of the crystalline rocks, arise from combinations of elements which are always the same, and whose total proportions in the mass containing them vary only within narrow limits. In seeking the mineral silicates, whose aggregation constitutes rocks, it is not necessary that each association forming a distinct rock mineralogically should also correspond to a special chemical composition of the Magma which produced it. This appears to me to constitute one of the most important views of the study of rocks, and the researches which I have undertaken on this subject have led me to results remarkable for the simplicity which they introduce into the history of igneous formations, and which, besides being founded on experimental data, appear to me to agree perfectly with geological observations.

All Igneous Rocks derived from two Magmas.—An immense number of consequences may be logically derived from the following proposition, the proof of which I shall furnish presently, viz.:—*That all igneous rocks, modern and ancient, were produced by two Magmas, which coexist below the solid crust of the globe, and occupy there each a definite position.*

These two Magmas have undergone but slight changes of composition from the most remote geological epochs; and, moreover, they differ essentially from each other by means of well-defined characters. The one may, from its excess of silica, be called the Acid Magma; while the other is comparable to a basic salt; for its silica is not in sufficient quantity to saturate its metallic oxides. The difference of silica in the two Magmas is in the proportion of 7 : 5. They contain nearly the same quantity of Alumina; but the Siliceous Magma contains from one and a half to twice as much alkalies, and more Potash than Soda, while the reverse occurs in the Basic Magma. The first is specially characterized by its poverty in earthy bases, and the iron oxides; of these, it contains from six to eight times less than the other.

The following Table gives the composition of these Magmas, and the specific gravities of the rocks derived from them.

TABLE I.

Proportions of Elements.	Silica.	Alumina.	Potash.	Soda.	Lime.	Magnesia.	Oxides of Iron & Manganese.	Water, Fluorine, Carbonic Acid.	Sp. Gr. of Rocks.	
									1st. Natural.	2nd. Vitrified artificially.
GENERAL LIMITS OF PROPORTIONS IN THE IGNEOUS ROCKS.										
1. Siliceous,	62 to 78	11 to 20	3 to 6	1 to 6	½ to 2	½ to 2	½ to 4	½ to 3	2·4 to 2·7	2·35 to 2.46
2. Basic, .	45 to 58	11 to 20	½ to 3	1 to 6	5 to 12	3 to 12	7 to 20	½ to 4	2·8 to 3·2	2·5 to 2·84
MEAN PROPORTION IN THE TWO MAGMAS.										
1. Siliceous,	71·0	16·0	4·5	2·5	1·0	1·0	2·5	1·2	2·65	2·40
2. Basic, .	51·5	16·0	1·0	3·0	8·0	6·0	13·0	1·3	2·95	2·72

By combining the results I have obtained by chemical and mechanical analysis with those of analyses already published by various mineralogists, I have established that igneous rocks of crystalline texture, and almost all compact or vitreous masses, formed by fusion, and wrongly considered as minerals, are derived from one or other of these Magmas. To the first are referable all the Granitic rocks, including the Eurites, Quartziferous Porphyries, and Petrosilex, the Trachytes, Phonoliths, Perlites, Obsidians, Pumices, and Lavas, with Vitreous Felspar. To the second belong the Diorites, Ophites, Euphotides, Hyperites, Melaphyres, Traps, Basalts, and Pyroxenic Lavas.

Origin of Mineralogical Differences in Igneous Rocks.—I should also remark, that if we analyze various kinds of the same group of rocks—granites, for example—we often find more difference in the relative proportions of elements, between two specimens of the same type of rock, than there is between granite and a rock altogether dissimilar in appearance,—say a Trachyte or Pumice. We should conclude from this fact, that in rocks derived from the same Magma differences of mineralogical composition arise less from their elementary composition than from conditions of pressure, temperature, and in general the circumstances of their cooling; that is to say, from conditions of an *external* rather than an *internal order.* The Magmas which have produced the igneous rocks are comparable to baths containing many metals in a state of fusion, and which, in setting, are divided into alloys, different, according to the circumstances of their cooling, even when the original bath has the same composition.

Products of the Zone of Contact of the two Magmas.—Moreover, the zone of contact of the two Magmas should give out products of an intermediate character; and this is, in fact, the case; and from this zone appear to arise the Syenites, the Protogenes rich in talc, the Trachytes rich in pyroxene and amphibole, and various porphyries which are intermediate between Granitic or Trachytic porphyries, and Amphibolic or Pyroxenic porphyries. These rocks, which may be called *hybrid rocks*, have petrographical and geological affinities of an unsettled character; they seem to belong, sometimes to the rocks of the first, and sometimes to those of the second Magma.

Permanence of Separation of the two Magmas.—The Upper Magma, which is rich in Silica, and poor in earthy bases and oxides of iron, possesses the least specific gravity; and in this respect there are differences among the rocks produced by the two Magmas, from one and a half to twice as great as between oil and water. The separation is still greater if, in place of considering the rocks in their natural condition, we compare the vitrified products obtained by their fusion: further still if we refer them to their liquid condition, there ought to be, according to Bischoff's experiments, between the rocks arising from the two Magmas, differences twice greater than those observed in their crystalline state, and, therefore, from three to four times greater than those between oil and water: from these facts may be deduced the necessary and permanent separation of the two Magmas.

Fluid Zone situated below the Solid Exterior Crust.—The solid crust of the globe, then, reposes upon a fluid zone, composed of two distinct layers: the upper, which is the most refractory, is only semi-liquid or pasty, in consequence of the predominance of Silica, which is characterized by its viscosity; the second layer, which contains much less silica, and which presents atomic proportions, ranging from a bisilicate to a sesquisilicate, is much more fluid and dense; and also appears to be very rich in the oxides of iron, especially in certain regions. From this source have emanated those great masses of Magnetic oxide which have burst forth after the manner of the igneous rocks; and which in Italy, and the Ural Mountains, as in Scandinavia, are connected with the amphibolic or pyroxenic rocks. In the upper layer are collected, by preference, the lighter or more volatile bodies, such as the alkaline metals, fluorine, boron, &c., &c.; and, in fact, it is in the granitic rocks arising from this layer, that we find commonly the fluo or boro-silicated minerals, as mica, topaz, tourmaline, &c., &c.

PART II.

ON THE CHANGES WHICH HAVE TAKEN PLACE IN THE COMPOSITION OF THE TWO INCANDESCENT LAYERS, FROM WHICH THE ERUPTIVE ROCKS HAVE EMANATED.

Comparative Chemical Composition of the Principal Types of Eruptive Rocks.—It has appeared to me interesting to investigate the changes which have taken place, from the earliest epochs of the globe, in the nature of the incandescent layers which constitute the seat of the eruptions: for this purpose it is necessary to compare the principal types of rocks which have burst forth during successive geological epochs. I have

To face page 5.

		Principal Types of Igneous Rocks.	Spe Nat Limits.	y n. Mean.
Siliceous Rocks.	Granitic Group.	Granites,	2·60 2·73	0·8
		Eurites,	2·58 2·70	1·0
		Petrosilex,	2·58 2·68	1·0
	Trachytic Group.	Trachytes,	2·60 2·70	1·0
		Trachytic Lavas,	2·58 2·64	1·5
		Phonoliths,	,,	3·2
		Trachytic Porphyry,	2·52 2·65	1·5
		Pitchstones and Retinites,	2·31 2·36	6·0
		Perlites,	2·34 2·40	3·7
		Obsidians,	2·25 2·55	0·6
		Pumices,	2·00 2·53	2·6
Degradation of Siliceous Rocks.	Trachytic.	Syenitic Granites,	2·63 2·75	1·0
		Andesites,	2·58 2·72	1·0
Hybrid Rocks.	Ancient.	Syenites and Syenitic Porphyries,	2·67 2·78	1·0
	Modern.	Trachydolerites,	2·70 2·85	1·0
		Ferrocalciferous Retinites, Perlites, and Obsidians,	,, ,,	1·0
		Ferrocalciferous Pumices,	2·00 2·57	1·6
Basic Rocks.		Diorites,	2·80 3·20	·0
		Euphotides,	2·85 3·10	·5
		Hyperites,	2·85 3·10	·6
		Melaphyres,	2·75 2·95	·5
		Basalts,	2·85 3·10	·2
		Dolerites,	2·85 3·10	·1
		Pyroxenic Rock, average composition,	,, ,,	·1
		Doleritic Lavas,	2·85 3·00	·0
		Leucito-augiticalciferous lavas,	2·72 2·90	·6
Degradation of Basic Rocks.		Serpentines,	2·50 2·66	·0

Th

determined their average composition, and the limits of the variations which take place in the proportions of their elements, both from my own researches and from the chemical analyses published by various writers, among whom I may mention, in particular, MM. Gmelin, Abisch, Dufrenoy, Ebelmen, Delesse, and Ch. Deville. The results at which I have arrived are contained in the annexed Table.

Changes in the Composition of the Acid Layer deduced from a Comparison of the two great Families of Siliceous Rocks.—The siliceous rocks comprise two great families: the Granites and the Trachytes: their separation is very definite chronologically, for the former belong to the primary or secondary periods, and the latter to the tertiary, quaternary, and modern periods. If, now, we compare the average composition of the two fundamental types of those families, granite and trachyte, and consider that they represent the most abundant products of the siliceous layer, we shall find that in the long course of ages that divide the primary and tertiary periods from each other, the following changes took place in the composition of the fluid mass which nourished the eruptions: viz., there was a diminution of $\frac{8}{100}$ or $\frac{9}{100}$ in the proportion of silica, and of $\frac{21}{100}$ in the potash; but that the proportions of lime and iron oxides were almost doubled, and that of soda tripled. If, again, we compare the composition of the trachytes of the tertiary period with that of the trachytic lavas of the actual epoch (and we may cite as a type lava that of the Arso, which was spread over the isle of Ischia in 1301), we shall find that the proportion of silica has diminished still further, remaining, however, greater than the quantity contained in the various rocks ejected from the basic layer; while the soda has increased by more than $\frac{50}{100}$.

Changes of Composition in the Basic Layer.—Let us see if changes of the same kind have taken place in the composition of the lower ferrocalciferous layer of fluid, including the Diorites, &c. The Diorites are the most ancient of the basic rocks, and were ejected the most abundantly in the earlier geological periods. But towards the end of the secondary period, and during the tertiary, they have been generally replaced by the pyroxenic rocks, which present three principal types, viz., Melaphyre, Basalt, and Dolerite. Their chemical composition is sensibly different, although they proceed from the same focus, and I have thought that to obtain the composition of the liquid layer from which they proceed, the best method would be to take the mean of the compositions of the three types. We thus obtain a general term of comparison, which

I have called in my Table, *Pyroxenic Rock of average composition,* and which represents the whole group of *modern basic rocks* as distinguished from the Diorites, which represent the *ancient basic rocks.* By comparing the numbers thus obtained with those presented by the Diorites, we can appreciate the changes which have taken place in the ferro-calciferous fluid layer, from the primary to the tertiary period. We see thus that there was a sensible diminution of silica and potash, and a notable augmentation of soda and lime. The proportion of soda has continued to increase still later, for our actual volcanic products contain still more than those of the tertiary period. The proportion of iron appears to have diminished rather than increased, but I should observe that the masses of magnetic oxide are connected with the Amphibolic rocks, and it is to this circumstance that the richness in iron of the Diorites is due, while a special cause tends to impoverish some of the actual volcanic products; that is, the influence of Chlorine, which carries away the iron in the state of vapour.

Similarity of the changes undergone by the Acid and Basic Layers.—We may recognise a remarkable similarity in the changes experienced by the Acid and Basic layers; in both there has been a decided diminution of silica and potash, while, on the contrary, the proportions of lime and soda have augmented. But the two layers remain, nevertheless, distinct, and the Trachytic products which represent the deeper portions of the siliceous layer differ much less in the whole of their elements from the Granites (even the most ancient), than they do from the Diorites, or any other product of the basic layer. As to the hybrid rocks which issue from the zone of contact of the two layers, my Table shows that, as well by their chemical composition as in their mineralogical character, they form a sort of tract of union between the two systems, although they seem to approach somewhat nearer to the siliceous rocks.

Causes of this Change of Composition.—The diminution of silica and potash in the modern rocks of the Acid and Basic group seems to me to arise from the fact, that those elements were concentrated towards the upper portion of the fluid zone, on account of their low specific gravity: and, on the contrary, the proportion of lime should increase with the depth. But the increase of soda in the eruptive products of the later epochs of the globe, an increase which becomes more and more decided down to our own epoch, and which is not in harmony with the changes in the proportions of the other elements, appears to me to be due to a special cause: it appears to be difficult to give an account of it, without admitting the intervention of sea-water in the formation of igneous products, at least during the later geological periods. Thus, like M. Abisch, I am led by my researches on rocks to consequences having points in common with the explanation which H. Davy had deduced from his studies on volcanic phenomena; but it does not appear to me to be necessary to suppose unoxidized alkaline and earthy metals to exist in the incandescent zone which covers the earth's surface.

Three orders of facts require the intervention of sea-water in volcanic phenomena.—The intervention of sea-water in volcanic effects appears to me to be based upon three great orders of facts:—

1°. The action of elastic fluids, much more marked at present than formerly, on the phenomena and rocks of eruption.

2°. The nature of these elastic fluids, among which are found in abundance aqueous vapour, hydrochloric acid, and the chlorides and acids of sulphur.

3°. The considerable increase of soda in the more modern of the igneous rocks, whether they be derived from the acid or the basic layer; I should add, that this substitution of soda for potash is accompanied by the replacement of fluorine by chlorine.

I might also add that many volcanic products contain, not merely organic matters, but, according to the observations of M. Ehrenberg, recognisable traces of organized beings, which prove clearly the addition of external elements in the formation of those products, whilst there is nothing similar in the ancient granitic rocks, which constitute purely *endogenous* masses. I am aware that there are certain difficulties inherent in the hypothesis of an intervention of sea-water in volcanic action, but these difficulties are not insurmountable; and we must, of necessity, take account of the whole of the facts I have noticed, as tending to the same conclusion.

Circulatory Movement of Soda.—We know, moreover, that the sodiferous silicates are more easily decomposed than the potassiferous silicates: thus in mineral waters, as in the sea-water, soda is the dominant alkali. It seems thus destined to a continual circulatory movement: removed from the rocks in decomposition by the infiltrated water, then, transported to the sea by running water, it is brought back by deep crevasses to the subterranean foci, from which it issues again, partly as vapour, and partly incorporated in the lavas.

PART III.

EXPLANATION OF THE DIFFERENCES IN CHEMICAL COMPOSITION AND MINERAL CHARACTER OF THE IGNEOUS ROCKS.

Having explained the changes produced, from the earliest epochs, in the chemical composition of the two fluid layers which form the seat of igneous eruptions, I now proceed to compare the composition of the various products derived from the same layer, and to explain the differences that occur in the relative proportion of their elements and in their mineral characters.

Atomic Relations of the Elements in the Rocks of the Siliceous Group.—I have investigated the atomic proportions between the Silica and Bases in the Magmas whose solidification has produced the pyrogenic rocks. They are represented in the following Table for the rocks of the Silicious group :—

TABLE III.

Atomic Proportions in Igneous Rocks of the Siliceous Group.	Granite.	Eurite.	Petrosilex.	Trachyte.	Trachytic Lava.	Phonolith.	Trachytic Porphyry.	Pitchstone.	Perlite.	Obidian.	Pumice.	Syenitic Granite.	Andesite.	Syenite.	Trachydolerite	Retinite.	Ferriferous Pumice.
Ratio of Alumina to the other bases,	3·57	3·45	4·67	2·94	2·37	2·82	2·71	4·83	3·70	2·52	2·41	2·30	1·93	2·06	1·87	1·00	1·98
Ratio of Silica to all bases (except iron),	4·15	4·37	4·82	3·25	2·70	2·30	4·39	4·34	5·00	4·10	3·87	3·65	3·18	3·02	2·52	4·43	3·43
Ratio of Silica to all bases (including iron),	3·96	4·07	4·28	3·04	2·48	2·16	4·18	4·02	4·66	3·71	3·54	3·37	2·78	2·59	2·20	3·79	2·90

Relation of Silica to the Bases.—We see that in all these rocks, with the exception of Trachytic Lava and Phonolith, the ratio between the quantities of oxygen of the silica and that of the alkaline and earthy bases is greater than 3 ; that is to say, there is more Silica present than would be necessary to form Tersilicates. This atomic proportion would also be generally higher than 3, if we supposed the oxide of iron to form an integral part of the silicates, which is not usually the case. It should be remarked, moreover, that the Micas, which form an integral part of the rocks of the siliceous group, are very far from containing 3 atoms of silica for 1 of base. Thus when, in solidifying, the Magma resolved itself into an entirely crystalline mass, the silica, which is generally in excess, became free in the form of quartz.

Atomic proportion of Alumina to the other Bases.—Let us now consider the proportions of the different bases. In Granite the proportion of the oxygen of the alumina to that of the other bases is 3·57 : 1. This is somewhat more alumina than would be requisite if the whole took the form of a felspathic mineral; for in all those minerals the characteristic oxygen ratio of R_2O_3 to RO is 3 : 1; the excess of alumina has gone to form mica, and oftentimes also, accessory minerals, such as garnet, pinite, tourmaline, emerald, topaz, corundum, spinelle, &c., &c. In the normal granite, whose composition I have given, there is about 35 per cent. of quartz, 40 to 50 of felspar, which absorb 8 or 10 per cent. of the alumina, or three-fifths; the remaining two-fifths go to the formation of mica and the accessory minerals in the proportion of 20 to 25 per cent.

Explanation of Mineralogical Variations in Granites.—It is easy to see that the same Magma, in solidifying, might, according to circumstances, take the form of a granite, sometimes richer in felspathic components (Orthose, with Oligoclase or Albite), and sometimes richer in quartz and mica.

It is to be remembered that there are two types of mica,—*one* ferromagnesiferous, uniaxal, containing 11 to 16 per cent. of alumina; the *other* potassiferous, biaxal, containing double the quantity of alumina.

The latter mica crystallized out in preference to the other, when there was present in the Magma abundance of potash and alumina, and iron mostly in the state of peroxide: thence resulted the granites with a white silvery mica. But when there was present in the Magma a certain quantity of magnesia and protoxide of iron, the uniaxal mica, of dark tint, was produced, sometimes alone, but more commonly accompanied by the white mica. I shall presently explain how it came to pass that, at the close of the second period, these latter micas occurred exclusively, as has been shown by the examination of igneous rocks, geologically modern. When the oxygen of the alumina contained in granite formed nearly three times the oxygen of the protoxides, very little mica was formed, and the Magma resolved itself into a Pegmatite more or less rich in felspar.

Relation of Petrosilex to Granite.—In a former memoir (Comptes Rendus de l'Académie des Sciences, tom. xx., p. 1277) I have shown that petrosilex is only a variety of granite, the compact state in which it occurs being due chiefly to the rapidity of its cooling; moreover, its composition differs generally from that of the granites proper by its containing more silica, less alkalies, and more alumina, as compared with the protoxide bases. Similar chemical characters are found in other *aphanic rocks* (compact or vitreous), such as Pitchstone, Retinite, Perlite, &c., which are also very rich in silica, and relatively poor in alkalies, especially potash. I am thus led to regard these two circumstances as unfavourable to crystallization, and especially the too high per-centage of silica, whose influence is, doubtless, connected with the property of passing into the viscous state on solidifying. In my first Memoir, published twelve years ago, I have made the remark that, if certain physical circumstances, and particularly the rapidity of cooling, have hindered Petrosilex and Eurite from assuming the crystalline state like a granite, a share of influence must also be attributed to certain differences in the chemical composition of the Magmas, especially to the great richness in silica and relative poverty in alkalies of the Petrosiliceous masses. Thus my present researches have resulted in giving to this observation a greater character of generality.

Development of the Mineral Elements in Trachyte.—Let us now pass to the felspathic rocks of the Tertiary, Quaternary, and present epochs. My Table III. shows that in these rocks, with the exception of Retinite and Perlite, the oxygen of the alumina, compared with that of the protoxide bases, is a little less than 3 : 1. There is, therefore, somewhat less alumina than would be requisite to convert the whole mass into felspar; consequently, either a portion of the Magma remains in the state of a paste, or minerals less aluminous than felspar are developed; but these cannot be the white biaxal micas, for they contain still more alumina than felspar. Thus we do not find these micas in the felspathic rocks posterior to the secondary epoch; but we find in them the ferromagnesiferous micas uniaxal and dark-coloured, containing only from 11–15 per cent. of alumina. Even when the quantity of this base is small, silicates are formed, of whose composition it is not a necessary part, such as Amphibole and Pyroxene. We thus see how these minerals, which seem peculiar to the rocks derived from the basic Magma, come to be developed in an accessory manner in the trachytic Magmas by virtue of the insufficiency of the atomic proportion of alumina.

It is by the examination—not of the absolute quantities, but of the atomic proportions of the various elements—that we arrive at those consequences which explain so simply the development of some minerals in preference to others in the interior of the igneous Magmas. The trachytes, for example, contain more alumina per cent. than the granites, and yet they present a less atomic proportion of this base, compared with the other oxides. From this chiefly arises the difference in the minerals associated with felspar in the two groups of siliceous rocks, the ancient and the modern.

Relations of Trachytic Porphyry and Phonolith to Trachyte.—I have still to explain how the trachytes which present an atomic proportion of silica to bases, of about 3 : 1, can be connected, on the one hand, with masses whose richness in silica exceeds the ratio of 4 : 1, such as the Trachytic Porphyries, the Retinites, &c.; and, on the other hand, with the Phonoliths, which present ratios between 2 and 2·3 : 1.

In his admirable work on Volcanic Rocks M. Abisch has considered Phonoliths as Trachytes modified by contact with sea water, on account of their richness in soda and per-centage of water. This view is correct, but appears to me to be insufficient: it does not explain, in fact, the high proportion of alumina in the Phonoliths, on an average from 20 to 21 per 100, and which occasionally rises to 24 per cent., although the addition of the soda and water to the trachytic Magma ought to diminish rather than increase the relative proportion of this base. But we may observe that alumina, which is found in excess in the Phonoliths, is found in defect in Trachytic Porphyry and in Perlite, which is related to the former as a vitrified product. These rocks contain only 10 to 14 per cent. of alumina, and it is the reverse with respect to silica, of which there are only 57 to 58 per cent. in Phonolith, whilst there are 72 to 74 per cent. in Perlite and Trachytic Porphyry. In consequence of these opposite relations, if we add equal parts of Phonolith and Perlite together, we have a mixture which presents nearly the composition of normal Trachyte, excepting a certain excess of soda and water produced by the addition of foreign elements.

It is, therefore, probable that Phonolith and Trachytic Porphyry are only the two opposite products of a *liquation* which took place in the midst of the fluid mass: they are, as it were, the two inverse alloys, into which we so often see a metallic bath divide itself.

Origin of Syenitic Granite and Andesite.—I explain in a similar manner the formation of two other species of rocks which occupy similar positions,—the one, in the ancient siliceous rocks, and the other, in the modern siliceous rocks,—viz., *Syenitic Granite* and *Andesite,* a trachytic rock deriving its name from the chain of the Andes. These rocks are the degradations which form a passage between the Siliceous and the Hybrid rocks, and which, by way of *liquation,* are derived from the one or the other system,—from the Siliceous rocks, by a slight diminution in potash and silica, accompanied by an increase of alkalino-earthy bases; or from the Hybrid rocks by an inverse change. In a preceding Memoir (Comptes Rendus de l'Académie, tom. xxiii. p. 958) I have already noticed degradations of this kind, presented by the Zirconian Syenite of the south of Norway; also, in the Vosges, M. Delesse has seen the Syenitic Granite forming the centre of the Ballon d'Alsace and other masses, degraded at its periphery, so as to present the characters of Syenite, and pass even into Diorite.

Effects of the same kind are shown by modern igneous rocks; thus, M. Abisch found only 64 per cent.* of silica in the Andesite which forms the mass of Cotopaxi, but he recognised 64 per cent.* in the rock which forms the crater. On the other hand, M. Ch. Deville has shown that at the *soufrière* of Guadaloupe and at Teneriffe, the volcanic products which occupy the higher levels are more rich in silica than those of the lower levels. Thus, the phenomena of *Liquation,* noticed by various observers, are not simple hypotheses, but ought rather to be admitted as facts; and they must have taken place below the crust of the earth, and in pouches or crevices of this crust, as well as at its surface. Moreover, these phenomena have natural limits, and, notwithstanding the apparent connexions which they establish between the two petrological series, there exists, nevertheless, a well-marked separation between the types of the Siliceous and Ferro-calciferous groups of Rocks.

Atomic Relations of the Rocks of the Basic Magma.—Let us now state the relations which connect the various rocks of the basic group, and seek the causes which have produced their differences of chemical and mineral composition. The following Table gives the atomic proportions of the elements contained in the rocks derived from the basic ferro-calciferous layer.

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* There is some error in these numbers.—TRANSLATOR.

TABLE IV.

Atomic Proportions of Rocks of the Basic Layer.	Diorite.	Melaphyre.	Hyperite.	Euphotide.	Basalt.	Dolerite.	Pyroxenic Rock of average composition.	Dolerite Lava.	Leucito-Augito-Sodiferous Lava.	Serpentine.
Atomic Proportion of Alumina to the other bases,	1·53	2·21	1·08	0·98	1·01	1·11	1·36	1·26	1·26	
Atomic Proportion of Silica to all bases, excepting iron,	2·24	1·85	2·06	1·80	1·94	2·12	1·96	2·00	1·91	1·39
Atomic Proportion of Silica to all bases,	1·78	1·63	1·67	1·53	1·57	1·62	1·61	1·60	1·67	1·33

Atomic Proportion of Silica twice less than in the Rocks of the Siliceous Magma.—Of all these rocks, Diorite is the only one in which the atomic relation of Silica to all the bases is much greater than 2 : 1; moreover, if we take account of the oxide of iron, which is an essential constituent of hornblendic Amphibole, pyroxenic Augite, &c., we see that, in the basic rocks, the oxygen of the silica is generally comprised between 1·50 : 1 and 1·75 : 1 for all bases; thus, this ratio is nearly twice less than in the rocks of the siliceous group; and we thus see how great a difference separates the eruptive products of the two fluid layers, when we compare them with reference to the atomic proportion of their elements.

General Absence of Orthoclase and Albite in the Basic Rocks.—As the ferro-calciferous mineral associated with the felspathic element in the basic rocks is usually a Bisilicate (Pyroxene, Hypersthene, Diallage), or the union of 3 atoms of Bisilicate with 1 atom of Trisilicate (Amphibole), it is plain that there is not silica enough left for the bases forming the felspar to combine as trisilicates; from this results the rarity of Orthoclase or Albite in the basic rocks; it is only in varieties of Diorite rich in Silica and approaching Syenite, that we meet with trisilicates, and even then it is rather Oligoclase that is met with. If, even in these Diorites, felspars have been formed as rich in silica as Oligoclase, notwithstanding the small atomic proportion of silica in the

Magma, this arises, in most cases, from the fact that there was produced at the same time, as if by a sort of liquation, ferro-magnesiferous Mica, Garnet, and often Epidote, minerals which are all protosilicates, and which must have left disposable a certain amount of silica: this may even have been sometimes sufficient to have become isolated, as Quartz, although the atomic proportion of silica to the bases was far below the ratio of 3 : 1. Moreover, Diorite does not always contain Oligoclase; we often find in it also, as M. Delesse has observed, Andesine, which is a bisilicate, or sometimes even Labradorite.

Felspathic Elements of the Basic Rocks.—In the basic group, the Amphibolic rocks alone contain felspars somewhat rich in silica, such as Oligoclase; the other rocks, which have Pyroxene, Hypersthene, or Diallage, for their ferro-calciferous element, contain, as felspars, compounds in which the alumina is always in the state of protosilicate, and in which the protoxide bases are in the state, sometimes of trisilicate (Labradorite), sometimes of bisilicate (Vosges Felspar of M. Delesse), and sometimes of protosilicate (Anorthite and Saussurite).

Sometimes the felspathic element is found replaced, either wholly or in part, by alumino-alkaliferous silicates, which have an atomic composition analogous to that of felspar, but very different crystalline forms: thus, Augite is sometimes associated, in the Leucitic Lavas, with Amphigene, which has the atomic formula of Andesine; in the Nephelinic Dolorites, with Nepheline, representing Anorthite; in the Basalts, with zeolitic minerals, which, as M. Ch. Deville* has remarked, may be considered as hydrated felspars.

Relative Proportions of Alumina and other Bases.—If we consider the atomic proportion of alumina and of the alkaline and alkalino-earthy bases, we see that in the basic rocks this ratio varies from 1·5 to 1; and since in all the felspars there are 3 atoms of oxygen in the alumina for 1 in the other bases, we see that the formation of the felspathic element has absorbed, together with all, or nearly all, the alumina, from $\frac{1}{3}$ to $\frac{1}{2}$ of the other bases; the alkalies have gone to form the felspars as well as a portion of the lime and magnesia; the remaining portion of these bases has served to form the ferro-calciferous and magnesiferous bisilicate.

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* And all other mineralogists.—TRANSLATOR.

To the other characters which I have already noticed as belonging to the rocks of the basic group, a new one must be added, viz., that the atomic proportion of alumina, relatively to the other bases, is generally twice less than in the rocks of the acid group; and consequently, the minerals which accompany the felspathic element (Amphibole, Pyroxene, Diallage, &c.) do not contain, in general, alumina as an essential ingredient; yet in the Diorites Mica is often present; but it is the ferro-magnesiferous Mica, which is twice less aluminous than the white Mica, and moreover is formed in this situation at the expense of the felspathic elements.

General Magnetic Attraction in the Basic Rocks.—I add that the various bases having entered into the combinations which have produced the felspathic, amphibolic, and pyroxenic minerals, there has usually remained an excess of oxide of iron, which has separated itself under the form of saline oxide (magnetic oxide), sometimes accompanied by titaniferous iron: thus nearly all these rocks attract the magnetised needle.

Relation between Melaphyre, Basalt, and Dolerite.—There are also produced, in the formation of the basic rocks, phenomena of liquation analogous to those which I have noticed in treating of the siliceous rocks: in fact, the Melaphyres are masses very rich in alumina, containing generally from 18 to 25 per cent., whilst in other basic rocks there are rarely more than 16 per cent. But if, on the one hand, the Melaphyres are so strongly aluminous, there are, on the other hand, pyroxenic rocks relatively poor in alumina, such as Basalts, certain Dolerites, and Diallagic rocks; there are even basic rocks containing only a minimum of this base, such as the Serpentines and masses of pyroxenic nature, such as Lherzolite. But there is no difficulty in admitting that the phenomena of liquation have divided the basic fluid into two alloys, of which one, strongly aluminous, formed the Melaphyres, whilst the other engendered masses of rock containing a greater or less quantity of ferro-calciferous and magnesiferous silicates.

Development of Zeolites in place of the Felspathic Element.—In solidifying, certain basic rocks, as Basalt, have retained water, a circumstance which has given rise to the formation of the aluminiferous hydrosilicates of the family of Zeolites, replacing in part the felspathic element (Labradorite). These hydrosilicates are accompanied not only by Augite and magnetic oxide, but often also by Peridote or ferro-magnesiferous protosilicate.

Leucito-Augitic Lavas.—In my Table of the composition of the basic rocks I have introduced the lavas called Leucito-augitico-sodiferous, and which are Dolerites or Melaphyres, whose Labradorite is replaced by Amphigene with soda base. We may cite, as examples, the actual lavas of Vesuvius. In a chemical point of view they differ little from Doleritic lavas (composed of Labradorite and Pyroxene), except by a less proportion of oxide of iron, and by the abundance of soda, which appears due to the intervention of sea-water.

Development of Garnets in Igneous Rocks.—There is another mineral which is not generally considered as forming an essential part of igneous rocks, but which is often found in them in great abundance, and with a certain regularity; it is Garnet, which has for formula

$$(\mathrm{A}, \mathrm{F},)\, \mathrm{Si} + (\mathrm{C}, \mathrm{M}, f, mn)\, \mathrm{Si}.$$

In consequence of its relative poverty in silica, and its richness in alkalino-earthy bases and oxide of iron, Garnet ought to be less abundant in the siliceous rocks than in the hybrid rocks, such as Syenite, or certain basic rocks; and it is, in fact, so abundant in the Amphibolic rocks that geologists have believed they ought to form a new species of this rock, under the name Eklogite. But, like the Leucite of some lavas, or the Nepheline of some Dolerites, the Garnet takes its origin at the expense of the felspathic element, for in its formation it has absorbed a great quantity of alumina. The same mineral is found also frequently associated with serpentine, where it appears to supply, to some extent, the want of felspathic elements.

General Principle of Explanation of the Differences of Chemical Composition and Mineralogical Character of Rocks.—To sum up. If we generalize the principle of the phenomena of liquefaction which tend to exhibit themselves in every mass in the state of igneous fusion, and composed of elements of different natures; if we take account of the facts established by geological observation and by chemical analysis, as well as of the phenomena which are produced under our eyes in founderies, we can explain, in a simple and natural manner, the inequalities in chemical composition of the rocks derived from the same fluid mass; if, moreover, we have regard to the atomic proportions of the various elements of each Magma, we can render an excellent account of the mineralogical differences in the rocks arising from them, and we may even predict what minerals ought to occur in the crystallization of given silicated masses.

The special physiognomy of modern Eruptive Rocks due principally to the influence of elastic gases.—I should add, that there is a special cause which powerfully contributes to give to modern eruptive products a special physiognomy, and also to enlarge the limits within which their chemical composition varies, especially in the case of elements capable of forming volatile compounds; this cause is, in addition to variations of pressure, the intervention of external elements, especially gases and vapours, which manifest their influence in the modern igneous products much more decidedly than in the ancient. This is the action that gives to rocks geologically modern their amygdaloidal texture, that renders them oftentimes scoriaceous and pumiceous; it likewise modifies the form of the orifices of eruption, which assume the form of craters placed on the summits of conical mountains.

Results that justify the division of the Igneous Rocks into two groups derived from different Magmas.—The investigations that I have just explained have brought out relations, physical, chemical, and geological, which connect together the pyrogenous rocks, so varied in their outward appearance; and the clearness with which these relations have become disclosed seems to me to confirm the proposition that I laid down at first, viz., that all the igneous rocks are derived from two fluid layers situated below the earth's solid crust, and of which the one is characterized by its richness in silica; and the other, poorer in silica and alkalies, contains an incomparably larger proportion of alkalino-earthy bases, and of oxide of iron, whilst it is also distinguished by very different atomic proportions. Moreover, the products of the first layer contain almost always, as an essential and predominant element, the only species of felspar which crystallizes in the *fifth* system (of Rose), while the various species of felspars which form integral portions of the products of the second layer belong, without exception, to the sixth crystalline system. The distinction which I have established is found thus confirmed, even in a crystallographic point of view; but it remains for me to verify whether it is in harmony with geological observations, and whether it permits us to render account of the successive eruption of the pyrogenous rocks of different ages.

PART IV.

EXAMINATION OF THE FACTS RELATING TO THE EMISSION OF THE IGNEOUS ROCKS.

The Igneous Rocks of the First Ages belong almost exclusively to the Siliceous Group.—The first pellicle that solidified on the surface of the yet incandescent globe was evidently formed by the uppermost layer, the lightest and most fusible; thence resulted the primitive granite. If we now examine the formation of the first ages, viz., the azoic slaty beds, the palæozoic rocks, and the lower secondary formations, we shall find that the pyrogenous rocks, which during those ancient periods rose to the surface of the globe, and which have covered a large portion of it, are composed almost exclusively of felspathic and siliceous rocks derived from the upper Magma, viz., granites, eurites, felspathic and quartziferous porphyries, and their derivations. In fact, a single glance of the eye at a geological map of Europe, shows that up to the Jurassic period the Amphibolico-Pyroxenic rocks, arising from the basic Magma, form rarely more than one-hundredth part of the space occupied by the siliceous rocks; they occur, in fact, only accidentally, as compared with these.

The eruption of the ancient Basic Rocks results from secondary and consecutive phenomena.—It is a general fact, as I have observed, in all the crystalline regions I have visited in the north of Europe, in Germany, in the Vosges, the Alps, the Pyrenees, and the west of France, that the emission of the basic rocks was constantly preceded by eruptions of granitic or euritic rocks, across which rocks we see them form veins, sometimes in great quantity. These subsequent eruptions belong, so to speak, to secondary and consecutive phenomena; and it is also remarkable to observe the amphibolic rocks concentrated, for the most part, in the zone occupied by the granitic rocks, or along the borders of that zone.

Origin of the general arrangement of Dioritic Rocks in dykes and masses traversing the Granitic Formations and the adjacent Beds.—Let us consider whether these facts are not in accordance with the consequences of my researches. In consequence of dislocations produced in certain parts of the earth's crust, the upper portion of the fused mass rises through the openings by virtue of the compression it experiences from the subjacent masses and the expansive power of elastic gases—thus are produced the great eruptions that bring to light the granitic Magma. But this ejection cannot take place without changing the conditions of equilibrium of the basic Magma situated below; a certain portion of it is in general drawn in, after the siliceous Magma, into the hollows and crevices of the terrestrial crust, where it preserves in part its heat and fluidity during the cooling of the great felspathic masses accumulated around the slits or orifices of eruption; these siliceous masses giving origin to chains of mountains, or hills of rounded contour, respectively. In solidifying, the granitic masses became contracted and fissured, and various causes of dislocation produced at the same time, in the adjacent stratified rocks, fissures or slits, through which were injected the still liquid portions of the basic Magma displaced in consequence of the eruption of the granite. Such appears to be the origin of the dykes, and more or less considerable masses of Diorite, which we see piercing the granitic formations and their surrounding rocks.

Lodes and Stockworks of Granite and Pegmatite.—Moreover, the interior portions of the siliceous Magma, not yet consolidated, gave rise to analogous effects, and produced those lodes and stockworks of granite and Pegmatite which have been remarked in most granitic regions, and which are distinguished from the surrounding mass by certain characters of composition or of texture.*

Succession of the various Phenomena.—The same series of phenomena must have been produced at different periods, sometimes in the same country, as I have observed in the north of Europe. Thus we see that a region where a great eruption has once taken place becomes the scene of secondary and successive eruptions, as volcanic phenomena prove to us at present, though on a different scale. Long after the emission of the stony products, the disengagement of gases and vapours continues, from which result metalliferous veins, and we must refer to the same source the emanations from thermo-mineral springs, which may be regarded as the last manifestation of igneous phenomena.

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* According to our experience, the difference is in texture alone, and not in chemical composition, which appears to be the same as that of the main body.—TRANSLATOR.

Change in the Mode of Eruption of the Basic Rocks during the second half of the Secondary Period.—Whatever be the reason, it is certain that the basic rocks, whose eruption took place during the primary geological periods, were formed merely by accident, as compared with the immense development of the siliceous and felspathic masses. It was during the second half of the secondary period that well-marked changes occurred in the nature of the rocks that rose through the terrestrial crust; when the upper layer of the fluid sheet had in general been much diminished in thickness, either in consequence of the eruptions, or of the solidification resulting from the radiation of heat into space. From this time forward, the substance of the lower layer, rich in earthy bases and oxide of iron, began to produce great eruptions, raising itself directly and in great masses from the central liquid zone; it possessed a degree of heat and liquidity much greater than at the former epochs, in which it formed only secondary and consecutive eruptions. Thus it was not limited to veins or masses of moderate dimensions, but was spread over the bottom of the seas, or the surface of the land, forming vast sheets of Trap and Basalt.

Eruptions subsequent to the Secondary Period.—It is further remarkable to observe, how in the modern epochs, as in the ancient, at places where the siliceous crust was still thick enough to give rise to considerable emissions, these eruptions have preceded those of the basic Magma. Thus, in Auvergne, and on the Rhine, during the Tertiary period, the outpouring of basalts succeeded large eruptions of Trachytic rocks. Likewise, before the creation of man, a considerable extent of the surface of Italy was covered by trachytic products, though at present, the eruptions of Etna and Vesuvius bring to light the products of the lower ferro-calciferous layer; for these products have Pyroxene as their chief constituent. This is not, however, universally the case over the globe, since the volcanoes of Iceland and of the Andes emit, generally, trachytic products, though poorer in silica and richer in earthy bases and oxide of iron than the ancient trachytes; as, indeed, ought to be the case, since the siliceous layer, from which these felspathic masses proceed, is at present almost completely exhausted, and ought to tend to merge in the basic layer, by the action of the elastic gases: we shall see also, further on, that many of the products of existing volcanoes are the result of the re-melting of matters ejected at anterior epochs.

Connexion between the ancient and modern Eruptive Phenomena.—I have just distinguished, in the eruptions of the ancient igneous rocks, two kinds:—

1st. *Eruptions of the first order,* arising directly from the fluid layers on which the earth's crust reposes.

2nd. *Eruptions of the second order,* or consecutive, having, as foci, masses of incandescent matter, which, instead of expanding outwards, have remained caught up in the interior of the crust.

The observation of the igneous phenomena of the later geological periods (tertiary, quaternary, and recent) seems to me to furnish a happy confirmation of this idea, and induces me to clear up the connexion that exists between earthquakes, volcanic phenomena, and the formation of chains of mountains.

General communication of Volcanic Chimneys with the secondary Foci.—If we consider the independence of action of volcanoes, even the most contiguous, and the extreme variability in the intensity of the eruptions, either of different volcanoes compared together, or of the same volcano observed at different epochs; if, moreover, we observe the extent of the zone affected by the eruptive action of each volcano; and finally, if we take account of the very small quantity of matter emitted in most eruptions—we recognise very speedily a want of proportion between such *minimum* results and the colossal power of a cause which could raise the liquid central mass from a depth of four or five myriameters. It is, therefore, probable that, in their ordinary state of activity, the volcanic chimneys do not communicate directly with the great incandescent layer, but that they are simply fed by the secondary foci, or pockets (as it were), of incandescent matter, which are situated at various depths below the surface.

Profound difference between Volcanic Phenomena and the Causes that produced the Chains of Mountains and Chains of Volcanoes.—Thus, the eruptive effects which take place at the mouths of volcanoes, either at intervals of time, or in a continuous manner, as at Stromboli, are merely local effects, of a secondary order, and completely distinct, both by their essential character and in the seat of their immediate cause, from those violent cataclysms which have given rise to chains of mountains, or to great lines of volcanoes. Hitherto the history of the human race has not recorded any of those grand phenomena that result from great ruptures, traversing the entire thickness of the terrestrial crust, and prolonged for considerable lengths; yet it is in these cases only that sufficiently great masses of incandescent matter have risen from the bosom of the fluid zone, to form important ridges on the surface of the globe.

Consecutive Phenomena of the great Ruptures of the Crust of the Globe.—On these great lines of fracture are situated, here and there, volcanoes arranged in chains, but the chinks penetrating downwards to the liquid internal zone are promptly obliterated throughout the greater part of their extent, and many volcanoes become extinct which have had only an ephemeral existence, as, for example, most of the ancient volcanoes of the interior of France: others have preserved a certain degree of activity, being fed by masses of matter contained in cavities of the terrestrial crust: others, again, of these volcanic foci appear to "revictual" themselves, from time to time, by chimneys penetrating more deeply, and representing portions of the primitive fissures, only half closed, and susceptible of being re-opened by violent commotions.

Extraordinary Eruptions estimated by the enormous quantity of Lava ejected.—It is probably at these epochs of re-opening of the deep fissures that certain extraordinary eruptions occur; such as that of Etna in 1669, which produced a volume of lava calculated at upwards of 600,000,000 of cubic meters; and that of Hecla in 1798, which poured out over Iceland a torrent of lava 80 kilometers long, by 15–16 kilometers broad. These extraordinary eruptions, however, are altogether exceptional, and represent what we may call the *crises*, or *acute periods* of volcanoes.

Incorporation in the Secondary Foci of Superficial Deposits.—The examination of the products emitted during ordinary eruptions shows that, instead of consisting of substances proceeding directly from the central fluid layer, they are composed, in part, of materials more or less belonging to the surface, and which have become ingulfed or incorporated in the secondary foci. Many lavas are the result of the re-melting of older lavas; thus, the Amphigenic products emitted by Vesuvius in our day appear to be only the "*rechauffée*" of the lavas of Somma, with the addition of soda; in like manner, the material of the lava stream of the Arso, in 1301, is trachytic, and of the same nature as the more ancient volcanic mass that produced the Isle of Ischia; also, according to the analyses of M. Abich, the eruptive mass of Monte Nuovo is no other than the Piperino of the Flegrean fields remolten.

Intervention of exterior Elements producing successively opposite Phenomena.—In this state of secondary or consecutive activity is manifested, in its highest degree, the intervention of external elements, belonging to the ground, surface water, and the atmosphere: often, in fact, deposits loaded with organic bodies have been ingulfed, and the introduction of sea water determines that enormous increase in soda which has been remarked in certain lavas, at the same time that it supplies the disengagement of elastic fluids, the influence of which is then preponderant. Such appears to be, in fact, the source of the principal elements of gaseous emanations, aqueous vapour, and the hydrogen which enters into combination with the chlorine and sulphur arising from the reduction of chlorides and sulphates, which reduction takes place by the contact of organic matter, or of bodies imperfectly oxidated, in the interior of the subterranean foci. But, by an opposite phenomenon, during their ascensional movement towards the surface, a part of the emanations, especially the hydro-sulphuric acid, undergoes a combustion at the entrance of the oxygen of the air, aspired through the fissures of the volcanic cones, as the recent analyses of M. Ch. Deville have established.

Change of burning Volcanoes into Solfataras.—When, in a subterranean focus, the heat becomes too weak to maintain the mineral masses in a state of fusion, the chimney that served for its excretory duct loses the characters of the burning volcano, and becomes changed into the Solfatara, and only returns to its former state in the rare cases in which the focus is again placed in communication either with the central liquid mass, or with other foci situated in the neighbourhood.

General Characters of Earthquakes compared with Volcanic Effects.—If we now examine earthquakes, we shall recognise in them characters totally different from those of volcanic phenomena. They give rise to no effect, either calorific or chemical; and, deducting the tremblings or shocks evidently connected with volcanic foci, the great earthquakes are distinguished by the vast extent of the zones shaken, which generally lie in particular directions. This property of linear and almost indefinite extension, directly opposed to the radiating and circumscribed action of volcanoes, shows that the two classes of phenomena have a different seat. When we observe that earthquakes are felt almost simultaneously at places distant from each other hundreds of leagues, we cannot doubt but that the seat of their action is situated below the terrestrial crust. The effects which we experience result from the transmission of disturbances imparted to the inner surface of this crust, at its contact with the incandescent liquid layer, whose surface is subject to various actions, physical and chemical: the elastic fluids, also, collected in this zone, appear to play an important part in those commotions.

Relations of Earthquakes to the Volcanic Zones.—Earthquakes are, in general, independent of active volcanoes, although they may react upon them, and even provoke eruptions. Those regions which are violently affected by shocks are related to the chief mountain chains, and especially the great volcanic zones, which represent the most recent lines of deep fractures, and it is evidently in the direction of these lines that their effects are most marked; in other respects they present variable characters, according to the nature, structure, and mode of superposition of the compartments of the exterior envelope.

Principal causes of difference in the mode of action of Volcanoes and Earthquakes.—The chief difference between earthquakes and volcanic phenomena consists in this, that the former have their seat, in general, beneath the crust of the globe, while the latter have their foci immediately below this crust, and consequently at much less depths, which renders more easy the opening and conservation of chimneys of communication with the exterior. Thence results the dissimilitude in their mode of action; the effects of earthquakes are almost exclusively mechanical, whilst, by virtue of the proximity of their foci, the manifestations of volcanoes are distinguished principally by calorific and chemical phenomena, in which the intervention of exterior elements, and especially surface water, appears to play an important part.

The formation of mountain chains cannot be attributed to Earthquakes.—However injurious they may be to man, earthquakes can only give rise to fissures of small extent, both in length and depth, and their indefinite repetition could not produce any of the great wrinkles that furrow the surface of the globe. The formation of chains of mountains, or of volcanoes, is, in fact, the consequence of ruptures effected in the entire thickness of the terrestrial crust; that is, across a depth of solid matter not less than 40 kilometers.* Such fractures require evidently the action of forces infinitely more powerful, the gradual development of which, according to M. Elie de Beaumont, appears due to the increasing excess in volume of the periphery of the globe relative to the internal mass, which contracted more and more, in proportion as the cooling was extended to greater depths.

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* That is to say, 25 miles. We do not know why M. Durocher fixes on 25 miles, as 2500 appears to be equally entitled to consideration.—TRANSLATOR

General Résumé.—Thus, the results which I have deduced from my researches, far from being at variance with geological observations, furnish a simple and natural explanation of the phenomena relating to the emission of igneous rocks; and clear up the relations which connect volcanic action and earthquakes with the formation of mountain chains. Thus we have seen revealed the mutual relations of the most varied igneous rocks, which form the branches (as it were) diverging from two distinct trunks; by resting on the laws and acknowledged facts of science, I have been enabled to render account of the inequalities that occur in their chemical composition, and the variations observable in their mineralogical characters. In place of that complex entanglement of igneous rocks which we see represented in the Tables of those learned geologists who have been pleased to figure the structure of the interior of the globe, we have only to conceive, inside the crust, a fluid zone presenting two distinct layers, and from which have proceeded, in succession, all the rocks which have been spread out over the surface, and which, having experienced the effects of *liquation*, more or less decided, have put on various forms, according to their conditions of cooling, and also according to the unequal action of gases and vapours, an action which manifests itself more decidedly in the more modern products. I might have further cited, as a new confirmation of the results of this memoir, the transitions observed for a long time in many countries between the various rocks of the same Magma, such as the passage of granite into quartziferous porphyry, eurite, and petrosilex; and their connexion with trachytic rocks; or, on the other hand, the passage of the Amphibole into the Pyroxenic and Diallagic rocks; but I have already treated of these facts in my preceding works.

PART V.

NATURAL CLASSIFICATION OF IGNEOUS ROCKS.

Classification of Igneous Rocks in three series.—If all the igneous rocks were derived from two Magmas, each of which has given rise to emissions from the time that it formed a first solid crust to the globe, it is plain that the classification of these rocks cannot be made according to one scale, but rather according to two great parallel series, each of which corresponds to one of the Magmas: moreover, there should be formed an intermediate series for the hybrid rocks. We are thus conducted logically to the classification exhibited by the following Table, which appears to me to reconcile the three sorts of analogies existing among the igneous rocks, viz., the chemical, the mineralogical, and the geological.

TABLE V.–

Divisions with respect to Age.		Divisic
I. PALÆOPYRIC ROCKS.		1. Cry
		2. Aph
II. MESOPYRIC ROCKS.	A. Rich in Magnesia.	1. Cry
		2. Aph
	B. Moderately rich in Magnesia.	1. Crys
		2. Por
III. NEOPYRIC ROCKS.	A. Tertiary.	1. Crys
		2. Por
	B. Quaternary.	1. Crys
		2. Por